RECRUITMENT OF THE DUSKY GROUPER (*EPINEPHELUS MARGINATUS*) IN THE NORTH-WESTERN MEDITERRANEAN SEA

by

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ABSTRACT. - Since 1986 the number of *Epinephelus marginatus* observations along the French coast of the north-western Mediterranean Sea has steadily increased. Observations collected in this study suggest a possible regular recruitment each year since 1996 along French coasts. Although this recruitment takes place in shallow water areas, small groupers (TL ≤ 40 cm) have been observed deeper. These observations allow us to propose an age-size relationship for the youngest groupers: 1 month old - 2/3 cm TL; 10 months - 5/7 cm; 1 year - 10 cm. Conclusions obtained from this study agree with previous parasitic and genetic studies and confirm the double way of arrival of groupers along the French coast: from Tunisia on the eastern part and from Morocco on the western part. Other factors that could be responsible for the present breeding and recruitment patterns include: a modification of the sex-ratio that now favours females, the partial protection of the species against spear fishing through a moratorium since 1993 (i.e., 10 years), and the recent warming of the Mediterranean. Due to the life-span of the species *E. marginatus* (more than 30 years) and the age of sex change (between 10 and 15 years old), recent increase of young groupers abundance has still few effect at a population level. Thus supporting the moratorium seems necessary to sustain a well balanced grouper population in the future.

RÉSUMÉ. - Recrutement du mérou brun (*Epinephelus marginatus*) en Méditerranée Nord-Occidentale.

Depuis 1986 le long des côtes françaises de Méditerranée, le nombre de signalisations de mérou brun (*Epinephelus marginatus*) a régulièrement augmenté. De plus, les différentes signalisations rassemblées dans cette étude montrent qu'un recrutement régulier semble avoir lieu chaque année depuis 1996. Ce recrutement se produit dans la zone peu profonde, mais des mérous de petite taille (LT ≤ 40 cm) ont été observés à de plus grandes profondeurs. Ces multiples observations permettent également de proposer une relation âge-taille : 1 mois - 2/3 cm ; 10 mois - 5/7 cm ; 1 an - 10 cm. Les conclusions tirées de cette étude sont en accord avec des études de parasitologie et de génétique précédemment réalisées et confirment ainsi la double origine des mérous des côtes françaises : tunisienne à l'Est et marocaine à l'Ouest. Plusieurs facteurs seraient responsables de l'actuelle reproduction et du recrutement observé: une modification du sex-ratio favorisant désormais les femelles, une protection partielle de l'espèce contre la chasse sous-marine, grâce au moratoire signé depuis 1993 (il y a donc juste 10 ans) et enfin un récent réchauffement des eaux de la Méditerranée. Mais la durée de vie importante de l'espèce *E. marginatus* (plus de 30 ans) et l'âge du changement de sexe (entre 10 et 15 ans) ne permettent pas encore d'apprécier un changement notable au niveau population. Le maintien du moratoire semble donc indispensable pour maintenir dans l'avenir une population équilibrée de mérous.

Key words. - Serranidae - *Epinephelus marginatus* - Grouper - MED - Recruitment - Age-size relationship - Depth distribution.

Since 1986, the number of observations of *Epinephelus marginatus* (Lowe, 1854) along the French coast of the north-western Mediterranean Sea has steadily increased. Moreover, a proportional increase of groupers less than 40 cm length has occurred (Francour and Finelli, 1991; Lelong, 1993). At the end of the 1980s, groupers sized 30 to 40 cm were observed along the coast of the department of Var, particularly in the Port-Cros National Park (Francour and Harmelin, 1988; Chauvet *et al*., 1991) and in the Natural Reserve of Scandola (Corsica) (Miniconi *et al*., 1990; Francour and Finelli, 1991). Since 1990, 10 cm total length (TL) groupers up have been reported in Corsica and along the coast of the Var (Lelong, 1993). A review of available data, published and unpublished, was initiated by Francour and Ganteaume (1999) who analysed about 150 grouper (TL ≤ 40 cm) observations. We collected new data and present in this paper a review of about 300 young grouper observations. Several hypotheses highlighted in the previous study (Francour and Ganteaume, 1999) were re-analysed and the recruitment of *Epinephelus marginatus* was characterised by addressing the following questions: Is the arrival of small groupers (less than 10 cm TL) along the Mediterranean French coast regular or not? Can we propose a hypothesis to explain the recent observations of young groupers? What is the effect of this recruitment at a population level? Can we identify the sites of breeding?

MATERIAL AND METHODS

This study reviews all the data on the dusky grouper *E. marginatus* of less than 40 cm TL in the north-western

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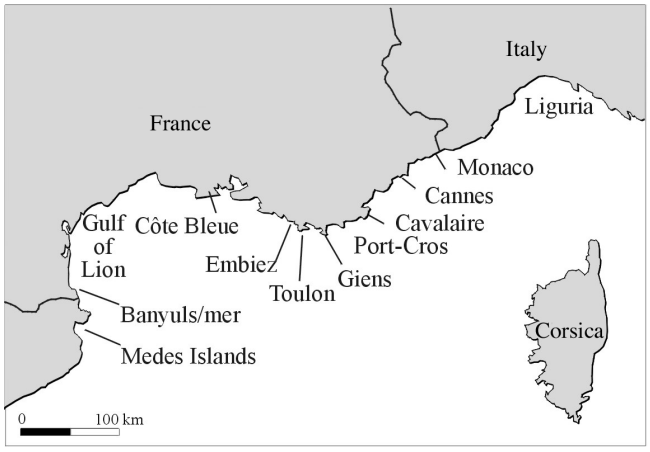
Mediterranean Sea collected since 1986, the year of the first observation of such groupers along the Mediterranean French coast. These observations of groupers were carried out by the members of the GEM (Groupe d'Étude du Mérou) or by French or foreign scientists (published data). In addition, questionnaires were distributed to SCUBA and free divers and with the help and support of the Biology Committee of the French Federation of Underwater Studies and Sports and different SCUBA diving clubs (unpublished data). The sites reported in this paper were not previously selected and young groupers were sought at random. The sampled area corresponds then to the area where SCUBA diving is performed along Mediterranean French coast.



The sizes of groupers reported here were mainly estimated *in situ* (SCUBA or free diving) using a 10 cm size class. Some trained observers (mainly GEM's scientists or members) were able to use a 5 cm size class to estimate total grouper length. In some cases (Côte Bleue Marine Park; Corsica), young groupers were caught by fishermen and kept alive in an aquarium (less than 10% of observations reported here). Before releasing accurate size measures were made.

The area of investigation in the western Mediterranean is mainly represented by Corsica, the coastline of the Alpes-Maritimes, the Var, the Bouches-du-Rhône and the Pyrénées-Orientales departments. More fragmentary information was obtained for Spain, Algeria, Tunisia, Italy and Croatia (Fig. 1).

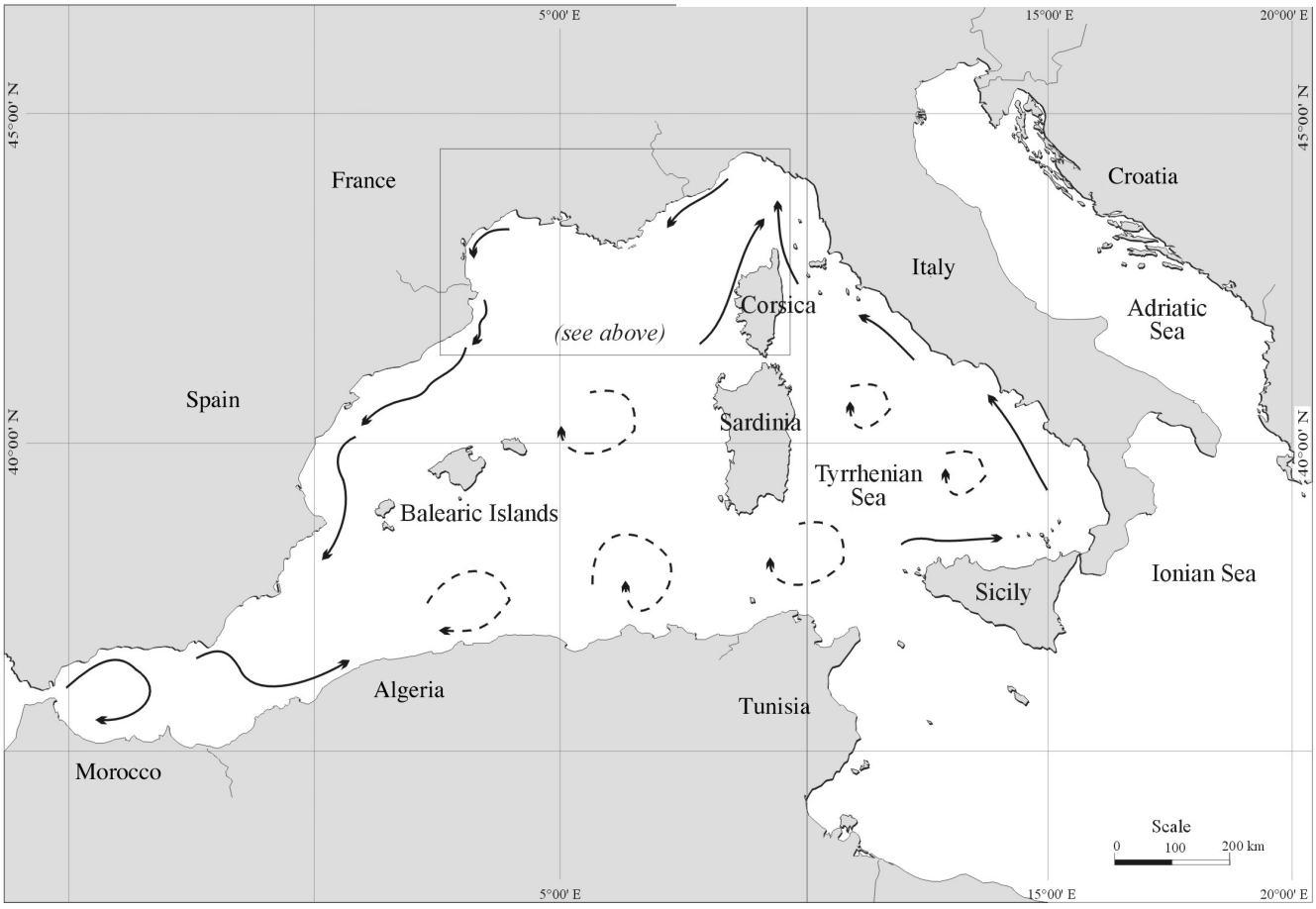


Figure 1. - Location of study areas in the north-western Mediterranean of *Epinephelus marginatus* of less than 40 cm (TL). Main surface currents are given (continuous lines: permanent currents [Liguro-provençal current]; broken lines: seasonal currents; simplified from Millot, 1987).

RESULTS

Distribution of size group according to depth

To analyse the possible relationship between depth and size of young groupers, individuals were classified into 8 size classes from 0 to 40 cm (Fig. 2). The smallest individuals (TL ≤ 25 cm) were more frequently observed in the 0-25 m bathymetric range. However, several individuals with a size between 20 and 25 cm were observed at a depth of 30 m and more. The largest individuals (25 < TL ≤ 40 cm) were regularly observed at depths of 15 to 60 m. All size groups are present in shallow waters (0-15 m depth). The biotope in which the small groupers were observed was often composed of littoral pebbles or screes.

Estimation of the period of recruitment and the age of the young groupers

Otoliths were not available for this study because most observed individuals were not caught. Figure 3 was established using only observations of groupers with a size of less than 10 cm (TL). At Le Brusc (Var), very small groupers (2 to 3 cm) were observed during a short period of time (September to October). In other sites, individuals belonging to the size class 5-10 cm had first seen in June in a few cases, but more often from July and August (Fig. 3). According to Marino *et al*. (2001), August probably corresponds to the spawning period. Therefore, the smallest *E. marginatus* observed (2 to 3 cm length) were probably 1 month old in September-October. The 10 cm length groupers observed in summer probably recruited the previous year and were then 10-12 months old.

Frequency of observations per year and per geographic area

Even if information concerning the Mediterranean coasts outside France is fragmentary and incomplete, the presence of small groupers (TL ≤ 20 cm) is a normal and regular phenomenon in the south of Spain (J. Mas, pers. com.; Barnabé, 1974; Grange and Grange, 1991) and along the North-African coasts (C. Chauvet, R. Semroud and D. Soltan, pers. com.). In Sardinia, the observation of small individuals of *E. marginatus* (15 to 20 cm) was unusual until 1989 (Russino *et al*., 1991). For the south of Italy and the Adriatic Sea (Croatia), the presence of small groupers (TL ≤ 25 cm) was reported for 1995 to 1999, but little information was collected concerning the last years to infer about *E. marginatus* assemblages in these areas.

For the French Mediterranean coasts, table I indicates measured or estimated maximum and minimum sizes of groupers observed between 1986 and 2001. The information was classified by areas, from the south to the north, then from the east to the west, i.e., in the way of the Liguro-Provençal current (Fig. 1). The first groupers of less than 10 cm (TL) were observed in 1989 in Banyuls (only one individual) and in the south of Corsica (several observations). Many small groupers were observed in Corsica (north and south) between 1990 and 1992, in 1996 and 2001 (south of Corsica). In 1992-1993, several observations were made along the coast of the Var, mainly in the Port-Cros National Park and in Les Embiez Island. During 1996-1997, new observations of small size groupers were made in Monaco and the Port-Cros National Park. In 1999, observations of small groupers were reported in the Côte Bleue Marine Park and in 2001 in the Port-Cros National Park and in the south of Corsica.

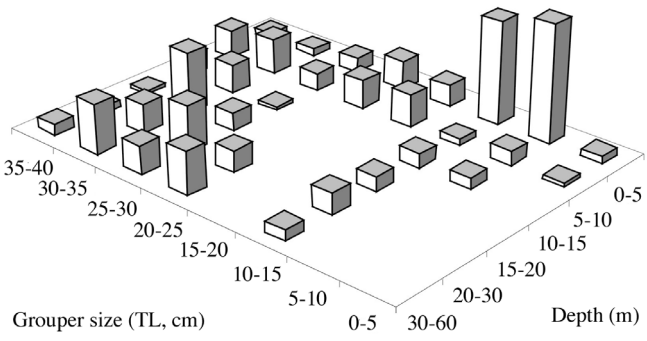


Figure 2. - Relative frequencies of abundance (in % of total number of individuals) for different size groups of *Epinephelus marginatus* (0 < TL ≤ 40 cm) according to the depth (in m).

DISCUSSION

A review of the available data allows us to highlight

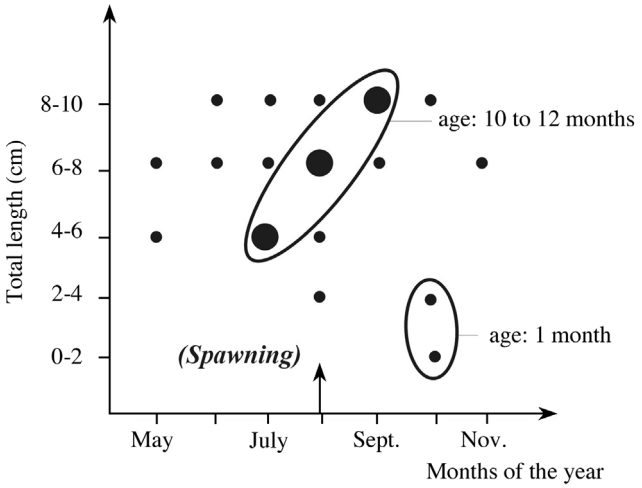


Figure 3. - Supposed age (in months) of the youngest *Epinephelus marginatus* observed according to the month of the year and body size (TL in cm). The black arrow shows the spawning period (according to Zabala *et al*., 1997a and Marino *et al*., 2001). Small black circles: less than 5 observations. Larger black circles: more than 5 observations.

some characteristics of the biology and ecology of young groupers. A clear relationship does not exist between the size of groupers and depth. According to various observations, juveniles less than 20 or 25 cm long were observed in shallow areas down to 10 m in depth. The smallest groupers (TL < 5 cm) were mainly observed in a depth of a few meters. The young groupers seem to prefer scree areas. No observation of young groupers was here reported for seagrass beds although some authors consider that young groupers may inhabit *Posidonia oceanica* seagrass beds (see references cited by Bruslé, 1985). Although, we observed one young grouper inhabiting a *Caulerpa taxifolia* meadow (5 m depth; TL = 35 cm, Cap Martin near Monaco), regular monitoring of this area allows us to ensure that it did not permanently use this habitat. The data reported here confirm that the smallest groupers inhabit shallow areas, the areas most exposed to anthropogenic pressure like pollution and angling (Chauvet, 1991; Azevedo *et al*., 1995; Derbal and Kara, 1995; Francour and Ganteaume, 1999; Harmelin and Harmelin-Vivien, 1999; La Mesa *et al*., 2002). However, the cryptic behaviour of young groupers (TL < 10 cm) involves a hazardous detection *in situ*. The data do not allow us to know if recruitment of *Epinephelus marginatus* happens only in these areas or elsewhere in a greater depth range. However, La Mesa *et al*. (2002) stressed that an important factor in determining the microhabitat suitability for juvenile groupers includes availability of shelter. As suggested by our data and La Mesa's study (2002), there is not necessarily a shift in groupers toward deeper waters with increasing size, but rather an enlargement of their bathymetric range.

In the literature only age-size relationships of adult groupers are available (Rafaïl *et al*., 1969; Chauvet, 1981; Bouain, 1984; Kara and Derbal, 1995). If we consider that spawning occurs during August (Bruslé, 1985; Zabala *et al*., 1997a; Marino *et al*., 2001), we can establish an age-size relationship for the first months of the life of the groupers: one month old groupers have an average size of 2-3 cm (TL), 10 months old, 5-7 cm and one-year-old, 10 cm. Battiato (1983) reported in October-December catches of 7.5-10 cm length young groupers. He supposed that eggs were fertilized in August of the previous year. Therefore the age-size relationships we propose for young fish agree with Battiato's work.

Until the mid 1980s only large groupers (TL > 50 cm) were observed along the Mediterranean French coast (Chauvet, 1991). Afterwards medium size groupers (30-40 cm TL) were reported in Corsica and along the coast of Var. The youngest groupers (TL < 10 cm) were observed in the south from 1989-1990 onwards, then in the north of Corsica (1990-1992), the coast of Var (1992-1993) and most recently in the Côte Bleue Marine Park (1999). A migration from the south to the north, then to the west, of medium size groupers seems to happen. This migration is consistent with the hypothesis of migration proposed by Chauvet and Francour (1989). In the same way the recruitment areas seem to move to the northern and the western, following the direction of the Liguro-Provençal current. A genetic study on groupers sampled in different areas is also consistent with the hypothesis of an exchange between north and south Mediterranean populations of *Epinephelus marginatus* and establishes a strong link between the French and the

Table I. - Synthesis of minimum and maximum sizes of less than 40 cm (TL) *Epinephelus marginatus* observed along the French Mediterranean coasts from 1986 to 2001. Bold: places and years yielding several observations of small individuals (TL < 10 cm).

Years	South Corsica	North Corsica	Liguria	Monaco Cannes	Cavalaire	Port-Cros	Giens	Toulon	Embiez	Côte Bleue	Golfe of Lions	Banyuls
1986-87						30-40						
1988	7-7	40-40				40-40				44-44		
1989	8-8					40-40	30-40					5-10
1990	**7-16**	**7-40**				8-40					20-30	
1991		**5-17**			30-40	30-40		4-4			20-30	
1992		**10-25**		15-15	30-40	20-40	30-40		**2-40**	40-42	20-30	15-40
1993	20-20	20-35				**10-40**	10-10		**11-13**	36-40		25-40
1994					30-40	30-40			22-22			30-40
1995		30-40			30-40	30-40	5-40	30-40				
1996	15-15	**5-10**	15-20		30-40	**5-40**						
1997	5-10	30-40	15-30	**10-35**	20-30	**10-40**	20-40	25-40	35-35			
1998	15-15	35-40	15-20	15-40		3-40	25-35	5-35	15-15	10-17		
1999	7.5-7.5	8-8			25-25	15-45	15-15	5-40		**7.5-40**		16-16
2000	7.5-15			15-40		7.5-15		8-8		15-15		25-25
2001	**5-15**			15-30		**7.5-25**		17-17				

Tunisian populations (Gilles *et al*., 2000). But this migration following the direction of the Liguro-Provençal current does not explain all observations. Groupers observed from 1989 in Banyuls and then in the Gulf of Lions may belong to a population of *E. marginatus* living in the north of Spain or coming from a Moroccan population. In this case, the migration of groupers could have happened against the Liguro-Provençal current. Analysing the parasitic fauna of groupers gills, Oliver (1992) proposed the hypothesis of a double origin of groupers present along the French Mediterranean coasts: the young groupers in the eastern part could come from the Tunisian area and groupers from the western part from the Moroccan area.

If the hypothesis of a migration proposed by Chauvet and Francour (1989) is correct, why were no observations of small size groupers made before 1986? Continuous survey of fauna and flora in protected areas like the Port-Cros National Park or the Natural Reserve of Scandola before 1986 revealed no small *E. marginatus* in the north of the Mediterranean. So the first observation of *E. marginatus* sized 40 cm (TL) dates from 1986-1987.

This migration may be due to a massive recruitment of groupers along the coast of Tunisia in 1982-1983 reducing the number of suitable habitats for the young *E. marginatus* (C. Chauvet, pers. com.). That could trigger young fishes to move northwards along dominant current searching for new suitable habitats. Movements between southern and northern populations could be explained by such strong recruitment events.

Before 1985-1990, large groupers, for the most part males (Bruslé, 1985; Chauvet, 1991), composed the population of *E. marginatus* along the French coast (Chauvet *et al*., 1991). After 1986, a modification of the demographic structure of the population happened, confirmed by the inventories carried out by the GEM in marine protected areas (Port-Cros National Park, Natural Reserve of Scandola) or non protected areas (La Ciotat, Monaco). In this way, in Corsica and along the coast of Var, the settlement of small size groupers (i.e., females according to Bruslé, 1985) has probably modified the sex-ratio, which previously favoured males: Zabala *et al*. (1997b) observed a 1:7 sex-ratio (sexually active males *versus* adult females). The breeding behaviour and spawning of gregarious animals such as groupers occurs within a socially structured population (Zabala *et al*., 1997b). Recent observations on the reproductive behaviour of *E. marginatus* in the north-western Mediterranean Sea (Louisy, 1996; Zabala *et al*., 1997b) showed that reproduction happens only when the ratio of females to males is sufficient in a given area. Thus, the recent modification of the sex-ratio in the population of the north-western Mediterranean Sea could have triggered a reproductive behaviour.

Moreover, the protection against underwater spear fishing brought by a moratorium since 1993 and the recent warming of the north-western Mediterranean Sea (Francour *et al*., 1994), are two other factors that could also have contributed to explain the increased number of young grouper observations. The warming of the north-western Mediterranean Sea could have an effect on the breeding of groupers because temperature greatly influences the development of larvae. Moreover this factor acts on the activity of larvae and on the time for hatching to occur (Dantart *et al*., 1999). So temperature would constitute an important factor in the observed recruitment process.

Only one of these three factors (sex-ratio change, spear fishing ban and warming) is not sufficient to explain reproduction and recruitment success: *e.g.*, a sex-ratio modification allows reproduction and juvenile production but without a spear fishing ban young survival could be reduced. So the present situation in north-western Mediterranean is probably a combination of at least 2 factors. However, a change in the sex-ratio or a strongly protection of groupers are essential.

The different observations of young groupers (TL < 10 cm) made in different areas studied allow us to make hypotheses concerning recruitment (Tab. II). In Corsica and Sardinia, recruitment occurred in 1990 and 1991 and each year from 1995 till 2001 (except perhaps in 1997). For the Corsica/Sardinia area, data concerning the year 1991 to 1994 are missing. For the French coast (Corsica excluded) recruitment occurred in 1991, 1992, 1994, and each year since 1996. The observations of groupers collected for the year 2000 are not sufficient to make conclusions about recruitment in 2001. In a few cases the very small size of observed individuals (TL < 5 cm) suggests that reproduction could have happened near the site of observation (Tab. II). In the other cases, recruitment was assumed after observations of one year old groupers the following year. The supposed breeding places agree with the hypotheses made by Louisy and Culioli (1999) about the known or suspected reproductive sites of the dusky grouper in the north-western Mediterranean Sea (Fig. 4).

In conclusion, from 1995 onwards, it seems certain that recruitment happens each year. Two or three factors could be responsible for this regular recruitment: the modification of the sex-ratio which now favours females, the partial protection of the species brought by the moratorium and the warming of the waters of the Mediterranean Sea.

On the other hand, due to the age of sex change (between 10 and 15 years old) and *Epinephelus marginatus* life-span (more than 30 years), the reproduction and recruitment events of the last ten years did not allow to renew the previous non reproductive population. Thus recent increase of young groupers abundance has still few effects at a population level. Consequently, supporting the moratorium seems necessary to enhance young grouper survival and to sustain

Table II. - Years of supposed recruitment (*) deduced from the French Mediterranean coastline and for Corsica and Sardinia. "Supposed breeding sites": Some observations of young groupers (TL ≤ 5 cm) born in the area, 1: Toulon; 2: Le Brusc; 3: Porquerolles; 4: Brandu (Corsica).

Years	French coastline	Corsica Sardinia	Supposed breeding sites
1990		*	
1991	*	*	1
1992	*	no data	2
1993		no data	
1994	*	no data	
1995		*	
1996	*	*	
1997	*		
1998	*	*	3
1999	*	*	
2000	*	*	
2001	?	*	4

a well balanced grouper population in the future.

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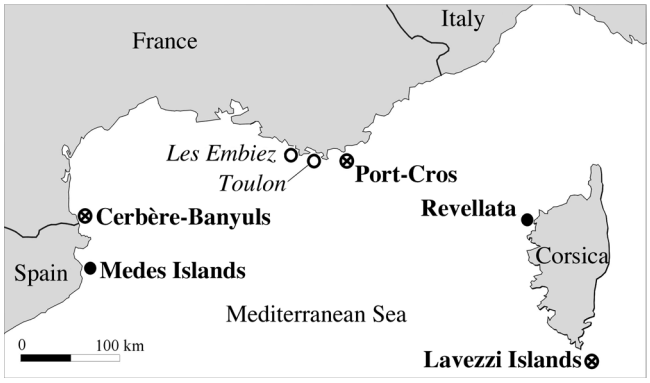

Figure 4. - Map of the main known or suspected reproductive sites of the dusky grouper in the northwestern Mediterranean Sea (modified from Louisy and Culioli, 1999). White circles: possible reproductive activity; circles with a cross: observed reproductive activity; black circles: observed spawns. Bold letters: marine protected areas; italic letters: unprotected areas.

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